State of California • State and Consumer Services Agency • Gray Davis, Governor
DEPARTMENT OF GENERAL SERVICES
Executive Office • 1325 J Street, Suite 1910 • Sacramento, California 95814-2928

February 23, 2000

The Honorable Steve Peace, Chair
Joint Legislative Budget Committee
State Capitol, Room 3060
Sacramento, CA 95814

Dear Senator Peace:

The Supplemental Report of the 1999 Budget Act, Item 1760-001-0666 contains language that requires the Department of General Services to submit a master plan on the Public Safety Microwave Network. Attached is the Report to the Legislature regarding the master plan.

If you have any questions or require additional information, please contact Christina Polley, Deputy Director, Telecommunications Division, at (916) 657-9482 or Karen Neuwald, Assistant Director-Legislation, at (916) 445-3946.

Sincerely,

CLIFF ALLENBY, Interim Director
Department of General Services

CA:CP:PW:pr\mwrpt.doc

cc: Michael J. Gotch, Legislative Secretary, Office of the Governor
Happy Chastain, Deputy Secretary-Legislation, State and Consumer Services Agency
Karen L. Neuwald, Assistant Director-Legislation, Department of General Services

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SUPPLEMENTAL REPORT--REVISED 1/4/2000

GartnerConsulting

Report to the Legislature
Public Safety Microwave Network Master Plan

STATE OF CALIFORNIA
DEPARTMENT OF GENERAL SERVICES
TELECOMMUNICATIONS DIVISION

18 November 1999

GartnerGroup

5950 Canoga Avenue, Suite 600, Woodland Hills, CA 91367

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1. EXECUTIVE SUMMARY

California's Public Safety Microwave Network (PSMN) is one of the largest public safety microwave networks in the world. The system covers more than 6,000 path miles, contains over 300 sites, and ten primary routes. It is available to all public safety agencies throughout the state including law enforcement, fire, special emergency, highway maintenance, forestry and conservation, and public services agencies. In order to provide enhanced capabilities to user agencies, the Department of General Services (DGS) embarked on an analog-to-digital upgrade for this system. Work on this project began in fiscal year 1993/94, and initial time estimates projected completion in fiscal year 2003/04. A report to the Legislature, delivered on November 29, 1995, provided an overview of the conversion plan along with a program schedule and cost analysis. This report stated the conversion was progressing on schedule and within budget and subsequently was approved by the Legislature.

The Supplemental Report of the 1999 Budget Act, Item 1760-001-0666, tasked the DGS with developing a Master Plan addressing the current status of the PSMN upgrade. In response to the Supplemental Report requirements, this report addresses the following issues:

- A confirmation that the microwave technology recommended by the DGS in its 1994 report continues to be the preferred option, in light of the current state-of-the-art in communications technology.
- A summary of the regulatory environment within which the system will operate, with specific emphasis on the impact of Personal Communication Systems (PCS) on the communications spectrum available to the network.
- A quantifiable summary of system usage by agency, including both state and non-state agencies.
- A comprehensive estimate of all costs associated with the analog-to-digital conversion, including the cost of tower and vault replacements, renovations, and modifications.
- A recommendation for an equitable allocation of the cost of conversion among those agencies.
- A schedule for implementation of the plan.

These six issues are discussed in detail in this report.

To accomplish the microwave system conversion, a number of alternative technologies were considered including satellite communications systems, utilization of Synchronous Optical Network (SONET) technologies, and exclusive use of commercially leased lines. As detailed in the report text, a study of each of these alternatives confirms that converting the PSMN from analog to digital technology more efficiently fulfills the requirements of user agencies and more readily accommodates potential mandates regarding the efficient use of radio spectrum.

As stated in the DGS 1994 Conversion Plan, the total cost of this program was originally estimated at $90 million. The cost allocation methodology initially developed and implemented by the DGS continues to be the preferred approach and, at this time, it is anticipated that project costs will remain within the original estimate. In line with the time frame developed in fiscal year 1994/95, this program continues on schedule with completion expected to occur during fiscal year 2003/04.

The DGS is confident that the approach outlined in the 1994/95 PSMN analog-to-digital upgrade plan will provide its customers with the wide-area digital network services they require today and in the foreseeable future.

2. Current Environment

2.1 BACKGROUND

In order to provide enhanced capabilities to user agencies, the DGS initiated an analog-to-digital upgrade for the PSMN in fiscal year 1993/94. Initial time estimates projected program completion in fiscal year 2003/04. A report to the Legislature, dated November 29, 1995, provided an overview of the conversion plan along with a program schedule and cost analysis. The purpose of the report being transmitted at this time is to:

- Provide reassessment and confirmation that the microwave technology recommended by the DGS in its 1994 report continues to be the preferred option
- Provide a reassessment of the PSMN in light of the current regulatory environment in which it operates and available communications technology alternatives
- Quantify system usage by user agencies
- Provide comprehensive estimates of future costs associated with the PSMN digital conversion
- Provide a recommendation for cost allocation among user agencies
- Update the implementation schedule for the remaining digital upgrade tasks

In 1996, the State of California, with the assistance of consultants, prepared and delivered California's Public Safety Radio Communications Plan (Strategic Plan). The purpose of the Strategic Plan was to:

- Identify and inventory current voice radio systems and capabilities.
- Analyze needs and requirements.
- Review technical and organizational alternatives.
- Perform a cost analysis which forecasted the one-time and recurring costs of the alternatives.
- Recommend actions for achieving the agency's vision of cooperative, shared communications systems.

The Strategic Plan identified lack of interoperability, channel congestion, aging equipment and limited functionality as critical deficiencies in the state's public safety communication infrastructure. The plan recommends that future public safety communication systems be built around digital technologies. The statewide digital microwave replacement program is intended to upgrade the existing microwave system in time to accommodate statewide system needs identified in the Strategic Plan.

Following the development of the Strategic Plan, a detailed Cost Benefit Analysis (CBA) was developed. The CBA contains the requirements for the radio systems, an analysis of the various alternatives including costs and benefits, a conceptual model of the proposed system design, and an implementation plan outlining the required steps and timetable to proceed with the improvements.

2.2 THE DGS CHARTER

The PSMN is under the charter of the DGS' Telecommunications Division. The Telecommunication Division's role is defined in the State Administrative Manual, General Policy Section 4500, dated February 1993. The Telecommunication Division's responsibilities include:

- Ensure the state agencies have the wireless and other telecommunications services necessary to meet their operational needs.
- Direct the consolidation and joint use of wireless and other telecommunications system resources used by state agencies.

The Division "ensures that statewide telecommunications management is timely, cost-effective, and efficient. It also ensures that the specialized telecommunications needs of public safety are met. This is accomplished through policies that maximize the state's resources and direct the consolidation and joint use of telecommunications systems and services where it makes economic, programmatic, and technical sense to do so."

The responsibility of the DGS with respect to microwave communications systems is identified under Government Code Section 14931.1. This section specifies that the department is responsible to "acquire, install, equip, maintain, and operate all new or replacement microwave communications systems operated by the state." The exceptions are "microwave equipment used exclusively for traffic signal and signing control, traffic metering, and roadway surveillance systems" and the university system, which is a separate legal entity. The Microwave Unit of the Telecommunications Division has the responsibility for program management of the microwave service.

Section 14931.1 also states "any system established shall be available to all public agencies in the state on such terms as may be agreed upon by the public agencies and the department." The only limitations to the use of the network are technology, budgets, and legal constraints.

2.3 CLIENT AGENCIES

The PSMN is available to all public safety agencies throughout the state including law enforcement, fire, special emergency, highway maintenance, forestry and conservation, and public services agencies. The current PSMN provides radio backbone infrastructure for the 12 state, county, and federal agencies shown in the following table.

• California Highway Patrol (CHP) • Department of Transportation (DOT) • California Department of Forestry and Fire Protection (CDF) • Department of General Services (DGS) Telecommunications Division (TD) • Department of Water Resources (DWR)	• Department of Fish and Game (F&G) • Office of Emergency Services (OES) • Parks and Recreation (P&R) • Teale Data Center (TDC) • Merced County (MER) • Federal Bureau of Investigation (FBI) • United States Coast Guard (USCG)

Table 1. Client Agencies

The CHP, the DOT, and the CDF account for over 75 percent of system utilization.

The CHP, the largest user of the PSMN, uses Very High Frequency (VHF) low band mobile radio systems to communicate between dispatchers and officers in their vehicles. VHF frequencies are used statewide to provide radio access to dispatchers from mobile radios anywhere in the state. In addition to the voice radio system, the CHP is implementing a pilot project outside of VHF low band for the use of digital mobile data terminals for its vehicles. The pilot project is envisioned as being the first phase of the statewide system, although the technologies used may not be duplicated in the future. The purpose of this first phase is to demonstrate and refine the concepts set forth in the Strategic Plan and the CBA through application of these concepts in practice.

The DOT has used VHF low band mobile radio systems to dispatch crews for construction, maintenance, and traffic operations. In recent years, the DOT has transitioned major metropolitan areas within the state to 800 MHz systems to improve its dispatch functions. Some 800 MHz systems are "trunked" to provide channel capacity on an "as needed basis". The DOT uses the PSMN as the communications link for its radio systems. The DOT also is investigating the use of digital mobile data terminals for its vehicles. The DOT has established that the use of digital technology is the only effective method to enhance their communications capabilities.

The CDF is currently operating on VHF high band and will continue to do so. As the existing equipment life cycle comes to an end, the CDF is planning to upgrade to a more sophisticated technology, which may include a migration to narrow band frequencies. Unlike the CHP or the DOT which both use microwave-controlled mountain top base stations to communicate with mobile users, the CDF uses a system of VHF high-band mobile relay stations.

The CDF mobile relay stations are typically accessed from an Emergency Command Center (ECC) via VHF radio. In some cases, an ECC may have remote mobile relay stations that are not accessible via a direct VHF radio path. Where this occurs, the CDF makes use of the PSMN.

The CDF also utilizes the PSMN for circuits that they refer to as intercoms. These are permanent party-line circuits that have connections to all ECCs as well as cooperating agency dispatch centers.

Client agencies other than the CHP, the DOT, and the CDF utilize the PSMN backbone infrastructure to support their communications requirements as given in Table 2 below:

Department of General Services Telecommunications Division	Engineering and maintenance traffic
Department of Water Resources	Operations and maintenance traffic
Department of Fish and Game	Dispatch and maintenance traffic
Office of Emergency Services	Fire Net Radio System, California Emergency Services Radio System (CESRS), fixed point-to-point non-mobile communications, Emergency Broadcast System (EBS)
Department of Parks & Recreation	Centralized dispatch and maintenance
Teale Data Center	Data transport
Merced County	Sheriff dispatch traffic
Federal Bureau of Investigation	Mobile radio and operations traffic
United Stated Coast Guard	Mobile radio and operations traffic

Source: DGS

Table 2. Other PSMN Users

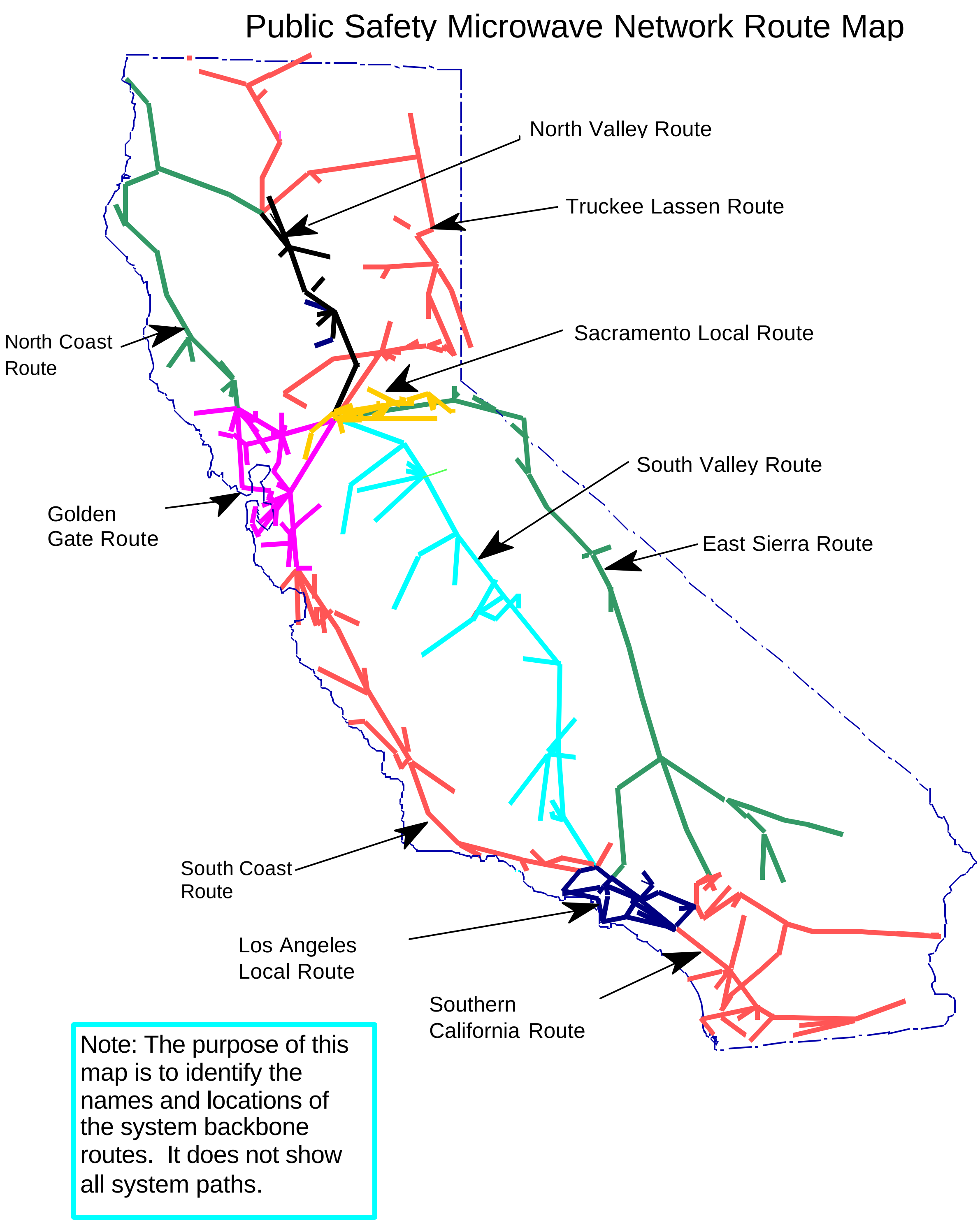
Currently the PSMN provides Public Safety Switching System (Green Phone) service to six state agencies. The Green Phone system is an emergency telephone system that utilizes the PSMN to transport voice traffic between public safety telephone users. Using the Green Phone system, users can call any telephone extension connected to the eleven PBXs located throughout the state. Currently there are approximately 700 Green Phone extensions used by agencies such as the CDF, the CHP, the DGS, the DOT, the OES, and the P&R. In addition to these telephone extensions, the Green Phone system is connected to the California Law Enforcement Radio System (CLERS), California Emergency Services Radio System (CESRS), and California Fire Department Mutual Aid Radio System (FIRENET).

2.4 NETWORK OVERVIEW

The DGS maintains a statewide microwave network consisting of over 300 physical sites, three network hubs, ten primary routes, and multiple single path routes connecting local users over a primary network backbone. The primary routes are:

- North Valley
- Sacramento Local
- South Valley
- South Coast
- Southern California
- Los Angeles Local
- Golden Gate Local
- North Coast
- East Sierra
- Truckee Lassen

Figure 1. PSMN Route Structure, shown on the following page, illustrates the primary routes and their locations.



Source: DGS

Figure 1. PSMN Route Structure

The PSMN carries over 1500 circuits serving 12 state, federal, and county agencies. The PSMN infrastructure provides voice and data channels by utilizing 0.96, 1.9, 2.1, 6.0, 10.0, 18.0, and 23.0 GHz microwave radios and associated equipment.

The DGS is currently implementing the analog to digital upgrade. Figure 2. on the following page, details the relative conversion status of each of the PSMN paths whether “complete”, “in progress”, or “not started”. The following summary shows the percent complete for each route:

- North Valley – 100 % complete
- South Valley – 20 % complete, 80 % in progress
- Truckee Lassen – 35 % in progress, 65 % not started
- LA Local – 30 % complete, 70 % in progress
- Southern Cal – 20 % complete, 80 % in progress
- South Coast – 25 % complete, 25 % in progress 50 % not started
- Golden Gate – 5 % in progress, 95 % not started
- Sacramento Local – 20 % complete, 80 % not started
- East Sierra – to begin fiscal year 2000/2001
- North Coast – to begin fiscal year 2000/2001

In accordance with the 1994/95 implementation schedule, the conversion plan is on target and the DGS does not foresee any significant issues that may negatively impact the remaining schedule.

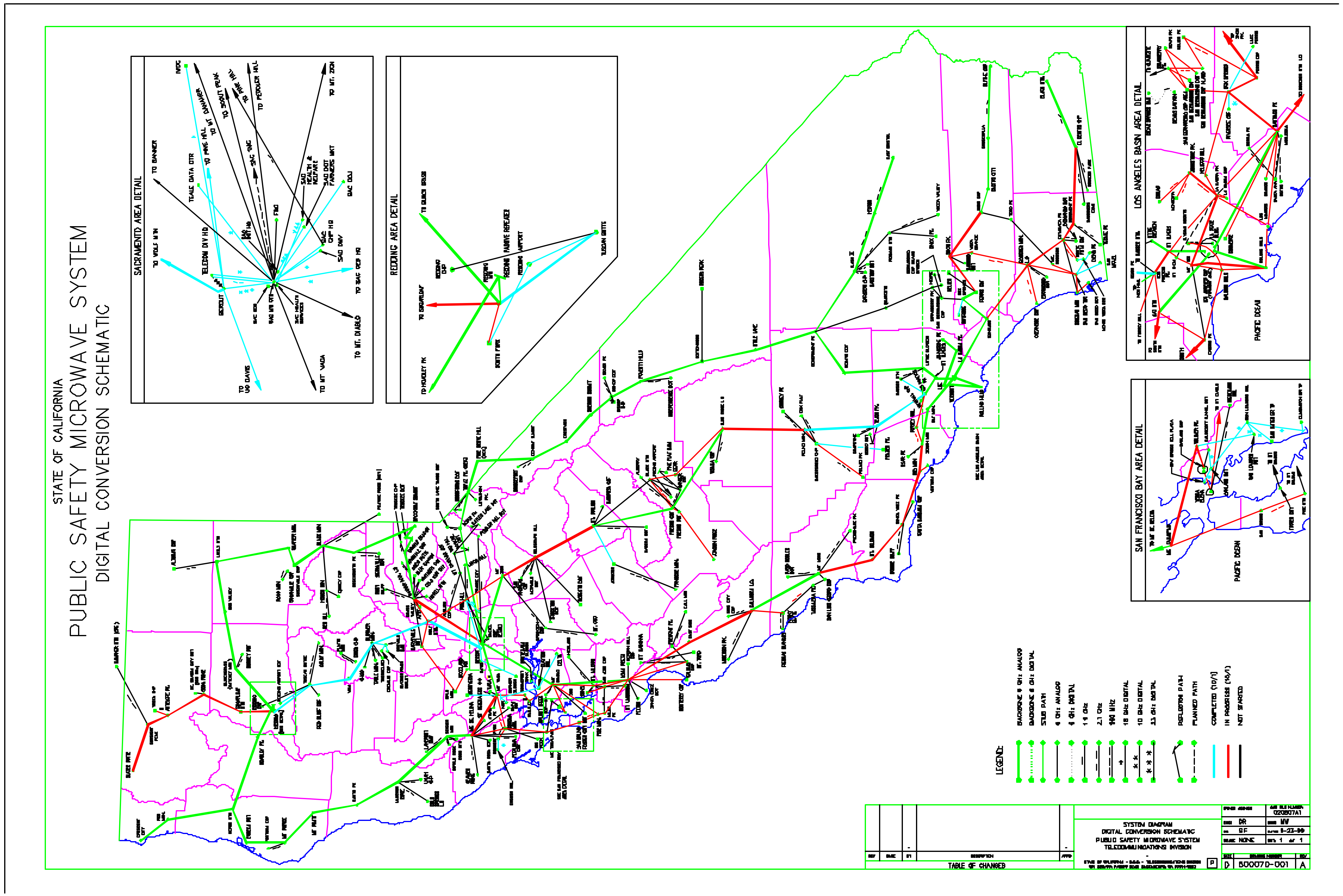
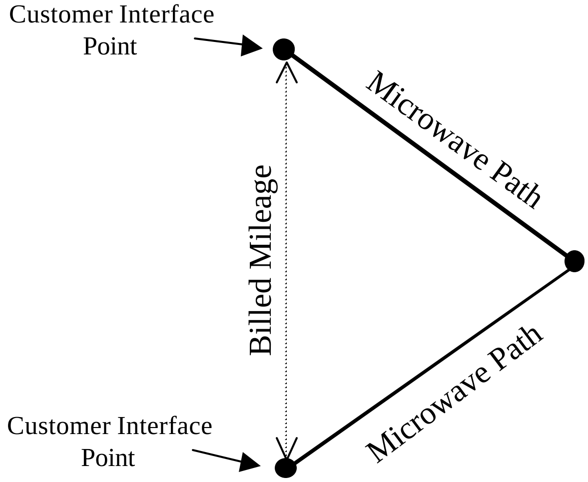


Figure 2. Route Conversion Status

2.5 QUANTIFIED SYSTEM USAGE

Client agency PSMN usage is measured as a percentage of total charges to all client agencies. Actual communications traffic is not measured for the purpose of agency billing because the service is provided on a 24 hours a day, 7 days a week, basis. Rather, these costs are derived on a circuit basis using the point-to-point mileage between circuit end points (customer interface points) and the number of customer interfaces (see Figure 3. below).



Source: DGS

Figure 3. Mileage Billing Methodology

For circuits providing voice service, mileage rates have been segmented into mileage bands. Discounts in the rate structure are provided to the customers as circuit lengths increase (see Table 3. below):

Mileage Band (Statute Miles)	Monthly Rate ($/Circuit)
First 10 miles (0 to 10)	9.11
Next 5 miles (11 to 15)	8.66
Next 5 miles (16 to 20)	6.51
Next 40 miles (21 to 60)	5.80
Next 40 miles (61 to 100)	5.70
Next 150 miles (101 to 250)	2.89
Next 100 miles (251 to 350)	2.18
Over 350 miles	0.71
Customer Interface	54.08

Source: DGS

Table 3. Analog Mileage Rates

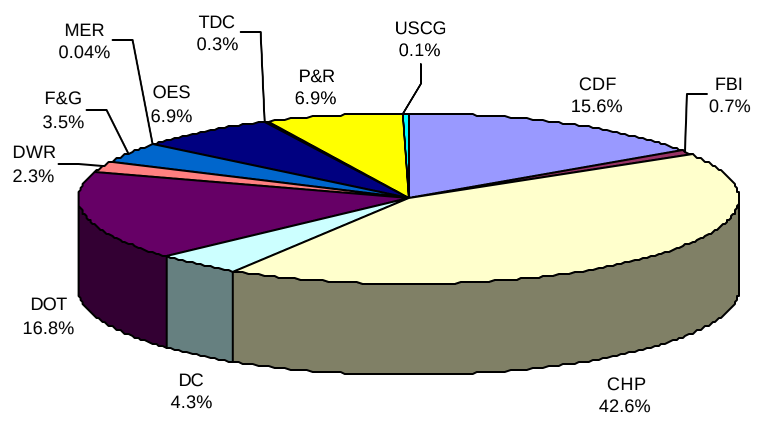
For circuits providing T1 type data service (such as DS0, DS1, and DS3) the billing structure uses a similar mileage band scheme; however, monthly rates increase with data capacity (see Table 4. below):

Mileage Band (Statute Miles)	Monthly Rate ($)	
DS0 (56 Kb/sec)	Fixed	Per Mile
First 50 miles	72.08	3.29
Next 50 miles	76.59	3.20
Next 500 miles	81.09	3.16
DS1 (1.544 Mb/sec)	Fixed	Per Mile
First 50 miles	288.32	13.16
Next 50 miles	306.44	12.79
Next 500 miles	324.36	12.61
DS3 (45 Mb/sec)	Fixed	Per Mile
First 50 miles	3,459.84	157.86
Next 50 miles	3,676.08	153.53
Next 500 miles	3,892.32	151.37

Source: DGS

Table 4. Digital Mileage Rates

Figure 4. below, details client agency utilization as a percentage of total billed cost based upon the circuit-mile billing methodology. Overall, PSMN utilization has increased approximately three percent over the previous year.



Source: DGS

Figure 4. Agency Utilization

3. REGULATORY ENVIRONMENT

The most significant regulatory impact to the state is the mandatory transition of incumbent microwave licensees from the 1.9 GHz and 2.1 GHz bands to the 6 GHz (or higher) bands. On January 16, 1992, the Federal Communications Commission (FCC) proposed to reallocate portions of the 1.9 GHz and the 2.1 GHz band from Fixed Microwave Services (FMS) to emerging telecommunications technology services, including Personal Communications Services (PCS). The FCC stated that it intended to accommodate the FMS licensees in a manner that would be most advantageous for the incumbent users, least disruptive to the public and most conducive to the introduction of new services. Accordingly, the FCC proposed that all new facilities in the 1.9 GHz and the 2.1 GHz band be licensed on a secondary basis to preserve the availability of the existing spectrum. On the following page, Figure 5. depicts the state's remaining 1.9 GHz and 2.1 GHz microwave paths.

Rather than clearing the FMS users from the 1.9 GHz and the 2.1 GHz band, the FCC proposed that the users be permitted to occupy the band on a primary basis until they could be relocated to another portion of the spectrum. The FCC also proposed to provide the PCS licensees with the option of requiring the FMS incumbents to relocate sooner if the PCS licensees paid for the additional costs caused by the earlier relocation. On April 25, 1996, the FCC adopted these new regulations regarding the licensing of FMS systems in the 1.9 GHz and the 2.1 GHz band.

For incumbent public safety agencies including law enforcement, fire, and emergency medical services operators, a three-year voluntary negotiation period from January 1997 to January 2000 is in effect with a two-year mandatory period immediately following. In the first phase, PCS licensees may negotiate with microwave incumbents regarding relocation. The second phase is a two-year mandatory negotiation period during which the parties are obligated to negotiate in good faith. The mandatory negotiation period is triggered at the option of the PCS licensee, but PCS licensees may not invoke their right to mandatory negotiation until the voluntary negotiation period has expired. Following the expiration of the mandatory period, incumbents who have not entered into negotiated agreements are subject to involuntary relocation under FCC rules.

For the state, the effect of the regulation is that for its existing 1.9 GHz and 2.1 GHz microwave paths, the costs of relocating to 6 GHz or other bands can be paid for by the new PCS licensees. Prior to the regulatory changes, approximately 30 percent of the PSMN stations were operating in the 1.9 GHz and 2.1 GHz bands. All but one of the state's 1.9 GHz licenses has subsequently been purchased by Pacific Bell Mobile Services, and the affected routes have been converted to 6 GHz. Pacific Bell Mobile Services has assumed all costs associated with the conversion. Auctions for the 2.1 GHz bands are ongoing and to date, no attempts have been made by the PCS providers to obtain the state's remaining 2.1 GHz licenses. The majority of the 2.1 GHz sites are not part of the main backbone of the PSMN. Consequently, they can be upgraded at a later date without significant impact to the network upgrade as a whole.

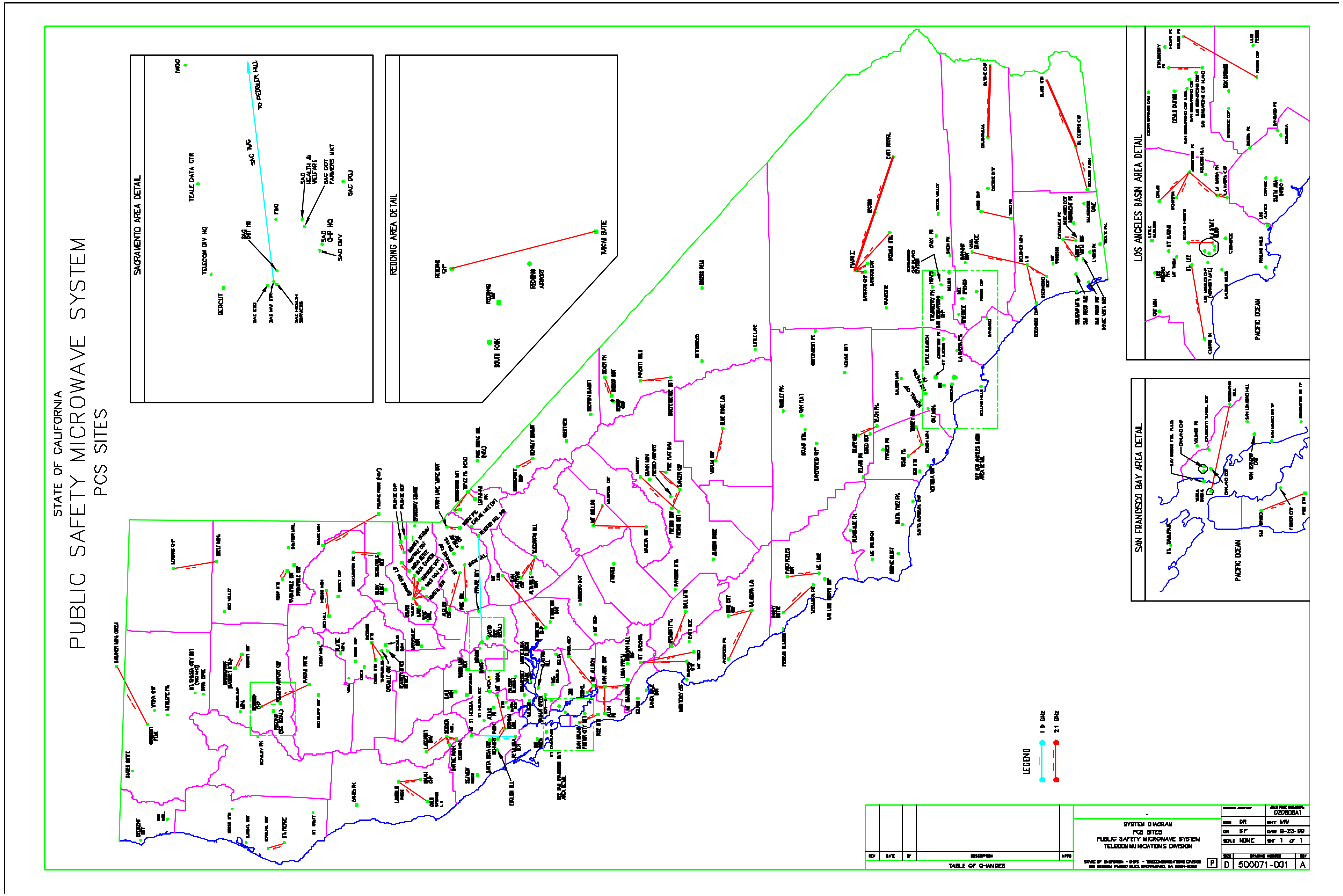


Figure 5. Remaining 1.9GHz and 2.1 GHz Paths

4. ANALYSIS OF ALTERNATIVES

4.1 PUBLIC SAFETY TECHNOLOGY TRENDS

The conclusions drawn in the Strategic Plan and CBA continue to be valid and relevant to the PSMN analog-to-digital conversion project. With the proliferation of digital voice and data communications throughout public safety agencies, the sole use of analog voice transmissions to convey the required information no longer meets the needs of users or the public served. The industry standard for all new networks is based on digital technology. Analog networks, similar to the PSMN, continue to be upgraded to digital technology due to the obsolescence of technology, and lack of industry support.

Most client agencies place a high level of importance on network management and security. No longer are networks a minor cost to an organization. Secure information transport is required. Digital technology has enabled organizations to upgrade their networks to meet the need for these industry trends. The importance of networks to the business environment and their cost mandate a well managed and secure network.

While few major networks are totally digital, the accepted standard is that all will become digital as required by business needs for network reliability and functionality. The driving force behind digital communications includes the need to have higher quality of service, improved security, enhanced maintainability, ability to transmit data at higher speeds, and the need for video conferencing and satellite services. Today's digital networks have become the backbone for application of technologies in public safety.

4.2 ANALOG VERSUS DIGITAL MICROWAVE TECHNOLOGY

Until recently, the decision to use either analog or digital technology in communications systems was not clear cut. Traditionally, analog technology, which uses the modulation of both frequency and voltage to convey information, had been the dominant technology and was generally considered the low cost, low risk solution. In the recent past, digital technology, which modulates voltage to transmit data (by representing information as a binary 0 or 1) provided superior performance, but was often considered too expensive and prone to reliability problems. Today, with improvements in digital technology and the general acceptance by telecommunications companies of digital as the new communications paradigm, the issue is no longer in doubt – digital transmission is now considered the preferred solution.

The primary benefits of digital microwave communications are superior audio quality, outstanding clarity of communications, and efficient use of spectrum. In any communications system, analog or digital, as the data signal travels through the propagation medium, it experiences both attenuation (weakening of the signal due to distance transmission losses) and noise interference (the addition of extraneous electromagnetic energy from outside sources like sunspot activity or electrical storms). In either type of system, unless the signal is periodically amplified through the use of repeaters, the signal will attenuate to a point where the data is no longer understandable. A repeater is a special radio that acts as both a receiver and transmitter.

Due to the complex nature of an analog signal, analog repeaters are unable to distinguish between the transmitted data and the accompanying noise. As a result, both the noise and the data signal are amplified and sent down the transmission path. After several iterations of attenuation, noise addition, and amplification of the signal, it becomes increasingly obscured by the noise and may become unusable.

4.2.1 Signal Regeneration

Like analog systems, digital systems also experience both attenuation and the introduction of noise. In a digital system, the repeater recovers the original data from the received signal. Amplification occurs only after the data has been captured and all noise stripped from the signal. Should sufficient noise be added to temporarily obscure the signal, digital communications systems can often reconstruct the signal using error correction processes. The result is exceptional signal clarity in a digital system.

4.2.2 Compatibility With New System

An additional consideration for a multipurpose system like the PSMN is signal conversion. If the PSMN is designed to function as an analog system, then all digital signals must be converted to analog format using modems (modulator/demodulators) prior to transmission. Alternately, if the PSMN functions as a digital system, then all analog signals must be converted to digital using A/D (analog-to-digital) converters. Although A/D conversion results in some signal fidelity loss, it still results in a much higher clarity than unconverted analog signal transmissions using an analog circuit. Additionally, A/D conversion equipment is much less expensive than the comparable modem equipment required to support an analog PSMN system. Furthermore, digital systems are able to tie directly into T1 links without the encumbrance or expense of modem interfacing equipment. As the use of digital information assets by public safety agencies increases, enhanced digital communications are becoming ever more important. Consequently, the investment in a digital PSMN should ensure improved performance and reduced costs for signal conversion equipment.

4.2.3 Support Costs

Increasing microwave system capacity for either additional voice channels or data bandwidth is becoming increasingly more expensive for analog systems. This is due in part to the fact that fewer manufacturers are supporting continued development of analog radio and multiplex systems. Since many telecommunications companies are installing all digital networks, manufacturers often cannot produce sufficient volumes of analog systems to benefit from economies of scale. This directly translates into higher prices for small orders of replacement or new expansion parts. The opposite is true for digital systems, which are becoming less expensive to manufacture due to the volume of sales of new equipment.

4.2.4 Features

Digital technology offers a wider array of features than does analog technology, and can more easily comply with potential mandates regarding the efficient use of spectrum. If industry trends continue as anticipated, digital equipment will likely replace most analog equipment in the near future.

The following table summarizes the advantages and disadvantages of analog and digital technology.

	Advantages	Disadvantages
Analog Technology	• Proven, reliable technology • Familiar operating characteristics • Uncomplicated technology	• Reduced audio quality with distance from broadcast site • Does not support high speed data streams • Equipment costs are increasing • Older technology; less vendor emphasis on development • Network reconfigurations are cumbersome • Vendor support decreasing • Additional conversion equipment cost
Digital Technology	• Equipment costs are decreasing • Spectrum efficiency • Enhanced audio quality in fringe areas through bit error correction • Improved privacy • Easily supports both voice and data transmissions • Reduction of signal noise and attenuation effects • Increasing vendor base • Easier network reconfiguration	• Technical complexity, more complex maintenance • Less familiar operating characteristics

Source: DGS

Table 5. Analog vs. Digital Technology

4.3 OVERVIEW OF AVAILABLE TECHNOLOGIES

4.3.1 Satellite Communications

In some respects, satellite communication systems are analogous to cellular phone systems. The primary difference between them is in the relative placement of the base stations in each system. In a terrestrial cellular phone system, base stations are located on earth. Satellite communications systems apply a similar approach but place the base station at much higher altitudes – either in Low Earth Orbits (LEOs) or in Geo-synchronous Earth Orbits (GEOs).

4.3.2 LEOs

LEO satellites circle the earth at relatively low altitudes – typically between 300 and 900 miles above the surface of the earth. The short transmission path afforded by the low orbit permits communications using comparatively low power radio signals. Thus, transmitters for LEO systems can operate with significantly reduced power ratings and with low gain, nondirectional antennas. Ground-based transmitters used with the currently operational Iridium satellite telecommunications system, for example, have an average output power rating of less than 0.6 watts and are somewhat larger than a 1980's-era cellular phone. As an additional benefit, the short transmission path all but eliminates transmission time delays that affect other types of satellite communications.

Unfortunately, the low altitude of a LEO system reduces the satellite's transmission footprint, effectively reducing the radio coverage of the orbiting base station. As a result, between 60 and 70 satellites are required to provide worldwide coverage. The Iridium satellite constellation, for example, consists of 66 active satellites and a number of in-orbit spares.

4.3.3 GEOs

GEO satellites orbit above a fixed geographical point on the surface. The critical altitude for geo-synchronous orbit is 22,300 statute miles above the surface of the Earth, which is more than 36 times the orbital altitude of a LEO system. Because of the increased distance, GEO systems require much stronger transmission signals. Until recently, that meant that a high power transmitter had to be coupled with a high gain antenna that was precisely aimed at the GEO satellite. Fortunately, advances in satellite communications have reduced both the transmitter power requirements and the antenna size required for effective GEO communications. Today, communications with GEO systems are possible from a unit that is not much larger than a laptop computer, with a transmitter power of less than 15 watts. However, there is still a noticeable time delay inherent to GEO systems producing gaps of up to one half second. This becomes problematic when attempting to conduct voice communications.

4.3.4 Satellites as an Alternative to Microwave

Despite recent improvements, broadband satellite communications are not yet viable as an alternative to the state's PSMN. Existing operational satellite systems have significant drawbacks as a direct replacement for the state's microwave backbone infrastructure. The following are key shortcomings of currently available satellite systems:

- Limited bandwidth
- GEOs are a single point of failure (i.e., only one satellite, with no redundancy, to support all users)
- Smoke from fires and heavy rain interferes with communications
- Dependence on satellite operator for service and support
- Some PSMN sites do not have direct line of sight to GEO satellites due to terrain masking or other obstructions
- High recurring cost

4.3.5 Satellite as an Alternative to Land Mobile Radio Systems

Another alternative is for the user agencies to replace their mobile and hand held radios with satellite systems. This approach would minimize the need for a PSMN. Numerous new satellite systems are in various stages of development and planning, but cannot be considered a viable alternative for several years to come. These new systems target the mobile telephone market, and will provide wide-area "roaming" capabilities similar to a typical cellular telephone service. Currently, of the vendors planning for LEO, GEO, and hybrid systems, none have a clear focus on the public safety community.

The following table summarizes the advantages and disadvantages of GEO and LEO satellite technology.

	Advantages	Disadvantages
Geo-stationary Earth Orbit (GEO) Satellite	• Wide area coverage • Reduced interference • Reduced initial investment • Available now • Accessible from remote areas • Ability to support voice and data	• Significant propagation delay • Reduced urban coverage (line of site) • No hand-held portable devices • Single point of failure • Low data rates • Limited talk-groups • Recurring costs
Low Earth Orbit (LEO) Satellite	• Extensive coverage • Little propagation delay • Reduced interference • Reduced initial investment • Ability to support voice and data • High data rates	• Entire system must be in place before operable • Limited availability • Undefined features and capabilities • Recurring costs • No planned dispatching services

Source: DGS

Table 6. GEO vs. LEO Satellite Technology

Satellite communications are not a viable option for primary public safety communications at this time due to limited in-building coverage capabilities and limited focus on dispatching capability; however, their unique features make them useful for secondary and ad-hoc communications requirements.

4.3.6 Leased Services

This alternative considers subscribing to a leased service provider to connect the radio backbone infrastructure for statewide voice and data communication. Because this approach contemplates leasing services in a similar fashion to leasing telephone service, it eliminates the requirement for the user to build out a private communications infrastructure. This alternative is only viable where access to the leased service provider is available such as urban areas.

One of the primary advantages of this alternative is that it eliminates the initial capital investment that would otherwise be required to upgrade the analog microwave network. Leased service providers are responsible for maintaining the infrastructure and providing the appropriate upgrades to support advancements in technology.

Connectivity for many of the existing communications systems throughout the country is supported by local telephone companies via leased lines. In some cases as with the PSMN, a hybrid approach is used where a combination of microwave and leased lines are both integrated to support the network. However, users have limited control over the leased circuits, which are susceptible to construction damage, earthquake damage, service outages and configuration problems. Also, leased services generally have higher long-term recurring costs than comparable microwave systems. Perhaps the most significant disadvantage of this alternative is the restricted availability of leased line service in some areas. In over half of the remote areas serviced by the PSMN, leased lines are not available.

Both microwave and leased line services support site connectivity for communication systems; however, microwave is the predominant backbone infrastructure for large wide-area communications networks. Rural sites necessitate that microwave be used rather than commercially leased services. In suburban areas, the option exists to utilize both microwave and leased services in a hybrid design. The following table summarizes the advantages and disadvantages of microwave and leased line services.

	Advantages	Disadvantages
Microwave	• Sole ownership and control of critical communications link • Improved resistance to damage from earthquakes and wildfires • Lower long term cost • Available in remote locations • Improved communications security • Ability to rapidly expand link capacity	• Higher initial cost • Technical complexity, more complex maintenance
Lease Line	• Reduced initial cost in established service areas • Reduced maintenance demands • Minimal cost of ownership issues	• Higher long term cost • Dependence on lease line operator for service and support • Capacity restrictions • Extremely high costs to establish service in remote locations • Longer service restoration times

Source: DGS

Table 7. Microwave Link vs. Lease Line

4.3.7 SONET Technologies

SONET technology is not, strictly speaking, an alternative to upgrading to a digital microwave network. Although it is not generally applicable to the type of public safety wide area microwave network required by PSMN user agencies, it is examined here to present a complete discussion of available technology.

SONET is an optical interface standard that supports fiber optic transmission rates from 51.84 Mbps to 13.27 Gbps. The key performance enhancement provided by SONET is the extremely high data transfer rates. A typical microwave system upgrade utilizing SONET can improve performance to 90 Mbps of communications capacity. However, SONET technology is not applicable to the type of wide area microwave network that the state requires. SONET is designed for extremely high capacity network links and the state's capacity requirements for mobile radio. Thus mobile data and station control do not justify a conversion to SONET. In addition, if the state elected to use SONET radio, relicensing would be required to support the increased bandwidth. The following table summarizes the advantages and disadvantages of SONET technology.

	Advantages	Disadvantages
	• Increased throughput capacity • Faster message switching • Higher growth potential • Allow interface with fiber systems	• Smaller vendor base • Increased system costs • Unsuitable for existing simulcast systems • Relicensing requirements • Additional training requirements

Source: DGS

Table 8. SONET Technology

5. ANALOG-TO-DIGITAL CONVERSION COSTS

5.1 BACKGROUND

The total cost of the conversion, as stated in the department's 1994 Conversion Plan, was originally estimated at $90 million. Of the $90 million, the DGS had anticipated that $20 million would come from the PCS providers in the form of payments to relocate existing 1.9 and 2.1 GHz paths to 6 GHz. The remaining $70 million includes $20 million for site upgrade costs attributed to the digital conversion, $29.6 million for digital microwave equipment, $16 million for additional equipment at sites, and approximately $4.4 million for major microwave equipment to be used in the Los Angeles Microwave Center relocation project.

5.2 COST ASSUMPTIONS

The following cost assumptions were used in the 1994 budget analysis to derive the $20 million site upgrade costs attributed to the analog-to-digital conversion project. A complete site-by-site reassessment has been completed to verify and update these assumptions as necessary. The 1999 CBA site improvement cost classifications of either "Major" or "Minor" also were utilized to better allocate actual costs.

5.2.1 Major Site Upgrade Assumptions

- Any site requiring complete reconstruction or major modification.
- Any site requiring new towers and vaults.
- Tower costs are estimated at $1,500 per linear foot. One hundred percent of these costs are attributed to the digital upgrade.
- Vault size and antenna requirements are chosen that reflect the basic needs of the PSMN.
- Sites that solely contain 1.9 GHz and 2.1 GHz paths are not included in the cost analysis. These costs are included in the PCS conversion costs.
- Sites upgraded under the Los Angeles Relocation Program are not included in this analysis.
- Vault sizes are dependent upon the number of paths per site and are based upon historical site developments (see Table 9.).

- Approximately 25 percent of the floor space for new vaults is required to support the digital equipment. The number of racks needed to house the new digital systems determines floor space (see Table 9.). Therefore, 25 percent of vault costs are attributed to the digital upgrade with the total vault upgrade cost dependent upon vault size. The following costs were estimated using both site construction costs from actual implementations as well as industry standard costs from representative vendors.

Vaults Size	Total Vault Cost
16 racks	$125,000
24 racks	$200,000
40 racks	$410,000

# Paths per Site	# Racks for Dig. Conv.	Vault Size (racks)	Tower Size (ft)
1	3	16	80
2	4	16	80
3	6	24	80
4	6	24	80
5	8	24	80
6	10	40	120
7	12	40	120
8	12	40	120
9	14	40	120

Source: DGS

Table 9. Vault and Tower Sizing Guidelines

5.2.2 Minor Site Upgrade Assumptions

- Sites not requiring reconstruction but must be upgraded to support digital equipment requirements including Heating, Ventilation, and Air Conditioning (HVAC) and backup power generation.
- Sites requiring additional short towers or reinforcement of existing towers.
- All minor vault upgrade costs are estimated at $20,000 ($5,000-7,000 for air-conditioning and $10,000-12,000 for backup generators).
- All minor tower upgrade costs are estimated at $40,000.
- 100 percent of these costs are attributed to the analog-to-digital upgrade project.

5.3 COST ANALYSIS

The PSMN costs are recovered through several funding sources. These sources of funding are outlined in the subsections that follow.

5.3.1 Division Microwave Replacement Program

The Division Microwave Replacement program funds the replacement of PSMN equipment that has reached the end of its service life. The depreciation schedule is based on an equipment service life of ten years. For the digital conversion project, the replacement program will be used to replace the aging 6 GHz analog equipment with new digital technology equipment (see subsection 5.3.4 below for the funding of the 1.9 GHz and 2.1 GHz equipment). Analog equipment removed from service is being used to support analog equipment still in service. The Division Microwave Replacement costs are recovered through the billing methodology described in subsection 2.5 on page 13. This source of funding is used by the DGS to provide the following microwave related services:

- The DGS labor (engineering, maintenance, and installation)
- Vault rental
- Microwave equipment depreciation and replacement
- Other (procurement, training, etc.)

This project remains within budget and on schedule with approximately $15 million in equipment replacement expenditures remaining.

5.3.2 Agency Additional Microwave Program

The Agency Additional Microwave Program uses agency funds for projects that expand the existing PSMN to meet emerging user agency needs. The DGS anticipates an agency program budget of $1.6 million for this fiscal year and expects an average of $2 million for the remaining three years of the upgrade program.

5.3.3 Los Angeles Microwave Center Relocation

The requirement to move out of the state-owned building at 107 South Broadway in Los Angeles prompted the relocation of the existing paths to other sites in the Los Angeles Basin. The completion of this project will result in the conversion of the affected sites to digital technology. This program was originally budgeted at $4.4 million for major microwave equipment while $12.3 million has been committed for the entire project. As of this date, approximately 80 percent of the electronic equipment has been purchased. Purchase of the remaining 20 percent is being delayed to minimize storage costs. Remaining items to be purchased are antennas and battery banks.

The following table shows the remaining allocation of funding sources for the conversion plan. It represents the spending authority for completion of the microwave conversion.

DIVISION FUNDING SOURCES FOR THE CONVERSION TO DIGITAL TECHNOLOGY OF THE PSMN							
Route	Fund	FY 99/00	FY 00/01	FY 01/02	FY02/03	Subtotals	Totals
Southern Cal	Replacement					$ -	$ 1,255,000
	Additional	$ 1,255,000				$ 1,255,000	
	LA MW Move					$ -	
Los Angeles Local	Replacement					$ -	$ -
	Additional					$ -	
	LA MW Move					$ -	
Golden State Local	Replacement	$ 3,290,000				$ 3,290,000	$ 3,675,000
	Additional	$ 385,000				$ 385,000	
	LA MW Move					$ -	
North Coast	Replacement		$ 2,490,000			$ 2,490,000	$ 4,290,000
	Additional		$ 1,800,000			$ 1,800,000	
	LA MW Move					$ -	
East Sierra	Replacement		$ 1,100,000	$ 3,910,000	$ 20,000	$ 5,030,000	$ 7,000,000
	Additional			$ 1,970,000		$ 1,970,000	
	LA MW Move					$ -	
Truckee Lassen	Replacement				$ 4,240,000	$ 4,240,000	$ 6,400,000
	Additional				$ 2,160,000	$ 2,160,000	
	LA MW Move					$ -	
Subtotals	Replacement	$ 3,290,000	$ 3,590,000	$ 3,910,000	$ 4,260,000	$ 15,050,000	$ 22,620,000
	Additional	$ 1,640,000	$ 1,800,000	$ 1,970,000	$ 2,160,000	$ 7,570,000	
	LA MW Move	$ -	$ -	$ -	$ -	$ -	
FY Subtotals		$ 4,930,000	$ 5,390,000	$ 5,880,000	$ 6,420,000	$ 22,620,000	$ 22,620,000

Source: DGS

Table 10. Remaining Allocation of Funding Sources and Spending Authority

5.3.4 PCS Relocation

As discussed in Section 3, the FCC has assigned PCS providers the same 1.9 GHz and 2.1 GHz bands that are used by approximately 30 percent of the PSMN stations. The FCC has mandated that the cost to relocate users to other bands must be paid by the PCS providers in return for access to their licenses. The DGS originally estimated that $20 million would be realized from relocation efforts of PCS providers.

With the exception of one path, Sacramento to Peddler Hill (see Figure 5. on page 17), all of the 1.9 GHz licenses have been purchased by Pacific Bell Mobile Services (PBMS). Under this agreement, PBMS provided the engineering services and replacement equipment necessary to convert each of the sites to 6 GHz paths utilizing digital technology. While not directly compensating the state for the equipment replacement costs, PBMS provided credits, whereby the DGS could obtain the necessary equipment from equipment vendors. The commercial value of these credits along with the value of the DGS and PBMS engineering and construction efforts is estimated at approximately $2.4 million in 1995/96 dollars.

Auctioning of the 2.1 GHz frequency band has not been completed. The state's licenses remain subject to the three-year voluntary negotiation period for public safety incumbents. As the PCS industry matures, we anticipate that the remaining 1.9 GHz and 2.1 GHz licenses will be purchased allowing for the digital conversion of those respective paths. Should this not occur for any reason additional funding could be required in future years to complete the analog-to-digital conversion program.

5.3.5 Site Upgrades

The 1994 Conversion Plan stated that there would be a $20 million dollar impact in agency site upgrade costs to support the analog-to-digital conversion. The calculation of site upgrade costs for the digital conversion project was based upon the assumptions stated in Subsection 5.2 on page 28. To validate this budgetary estimate, the DGS completed a site-by-site review identifying which sites require upgrade. Sites subject to upgrade under the Los Angeles Microwave Center Relocation project and PCS Relocation were excluded from the analysis.

Using the basic assumptions from the 1994 Conversion Plan as a starting point, updated cost estimates for vault and tower upgrades were made. A total of 168 of the 311 physical sites were identified as requiring either major or minor upgrades. Based upon these revised estimates and the site-by-site review performed by the DGS, the current projected site upgrade cost attributed to the PSMN analog-to-digital conversion project is $20.9 million. Site replacement or upgrade costs are recovered at the expense of the agency maintaining site ownership.

The major user agencies were contacted regarding the cost allocation methodology and given an opportunity to recommend alternative approaches. All of the agencies surveyed concurred with the current cost allocation approach developed and implemented by the DGS.

6. Conclusions

The DGS was tasked by the Supplemental Report of the 1999 Budget Act, Item 1760-001-0666 with developing a Master Plan for an assessment of the existing Public Safety Microwave Network upgrade program. Based on the information developed in the previous sections of this report, we present the following conclusions regarding the six topics of interest.

Reassessment and Confirmation of Technology

We analyzed the technological environment in which the microwave system is currently operating. We considered other long haul, point-to-point transmission technologies available as well as communications technologies that the existing microwave system must support now and in the future. Analysis of these technologies resulted in the following conclusions.

- **Satellite communications are not a viable option for primary public safety communications at this time –** GEO satellites provide the only viable service available but can be a single point of failure. Further, heavy signal degradation can result from environmental conditions and the transmission time delays are unacceptable for most public safety applications. Their unique features, however, make them a viable alternative for secondary and ad-hoc communications requirements.
- **Exclusive use of landline services in lieu of the existing microwave system is not feasible –** In over half of the remote areas serviced by the PSMN, landlines are not available. In addition, in the case of leased circuits, users have limited control and these lines are susceptible to construction damage, earthquake damage, service outages, and configuration problems. In particular, rural sites necessitate that microwave be used rather than commercially leased lines.
- **Conversion to SONET technology is not justified –** If the state elects to increase capacity by using SONET radio, relicensing would be required to support this increased bandwidth. More importantly, the state's current and projected capacity requirements for mobile radio, mobile data, and station control do not justify a wholesale conversion to SONET.
- **Digital microwave technology continues to be the appropriate option –** Converting the PSMN from analog-to-digital technology better supports the needs of the user agencies through ease of maintenance and lower equipment replacement costs. As the users need for information increases, digital transmission technology can better support and keep pace with these increasing requirements. Older analog technology microwave systems simply cannot support increasing system capacity requirements for additional voice and data channels in a cost-effective manner.

Summary of the Regulatory Environment

- **Continued conversion of the state's remaining 1.9 and 2.1 GHz paths is anticipated –** The most significant regulatory impact to the state is the mandatory transition of incumbent microwave licensees from the 1.9 GHz and 2.1 GHz bands to the 6 GHz and higher bands. The effect of this regulation is that the existing 1.9 GHz and 2.1 GHz microwave paths may be relocated to 6 GHz or other bands and this digital upgrade and relocation will be paid for by the new PCS licensees.

Before any changes, approximately 30 percent of the PSMN stations were operating in the 1.9 GHz and 2.1 GHz bands. All but one of the state's 1.9 GHz licenses has subsequently been purchased by Pacific Bell Mobile Services, and the affected routes have been converted to 6 GHz. Pacific Bell Mobile Services has assumed all costs associated with the conversion.

Summary of System Usage

- **The CHP, the DOT and the CDF continue to be the largest users of the PSMN –** However, the system provides service to many other agencies as well. The overall system usage, by agency, is detailed in Figure 4. on page 14.

Analog-to-Digital Conversion Costs

- **The analog-to-digital upgrade project remains on or near budget for each program element –** Expenditures for the digital microwave equipment and Los Angeles Microwave Center relocation project remain on budget. From the PCS providers, service, equipment, and credits valued at approximately $2.4 million in 1995/96 dollars have been received. As the PCS industry matures, we anticipate that the remaining 1.9 GHz and 2.1 GHz licenses will be purchased allowing for the digital conversion of the remaining sites.

  A review of site upgrade costs indicated that a total of 168 of the existing 311 physical sites required either major or minor upgrades. Based upon updated cost estimates and a site-by-site review performed by the DGS, the current projected site upgrade cost attributed to the PSMN analog-to-digital conversion project are $20.9 million.

Allocation of Costs

- **The current cost allocation methodology continues to be the appropriate option –** The major user agencies were given an opportunity to recommend alternate methodologies and subsequently concurred with the current approach. Cost recovery for the analog-to-digital upgrade project will continue under the cost allocation methodology developed and implemented by the DGS. The overall costs associated with conversion of the individual microwave paths comprising the PSMN consist of several components. These are grouped most logically into the following program elements:
  - Division Microwave Replacement Program costs
  - Agency Additional Microwave Program costs
  - Los Angeles Microwave Center Relocation costs
  - PCS Relocation costs
  - Site Upgrades costs

Costs for the Division Microwave Replacement Programs are recovered through the fees charged to user agencies for use of the system. Actual communications traffic is not measured for the purpose of agency billing because the service is provided on a 24 hours a day, 7 days a week basis. Rather, these costs are derived on a circuit-mile basis as described in Subsection 2.5 on page 13. Site upgrade costs are incurred by the agency maintaining site ownership.

The major user agencies were contacted regarding this cost allocation approach and given an opportunity to recommend alternative schemes. All of the agencies surveyed concurred with the current cost allocation approach developed and implemented by the DGS. Agencies maintaining ownership of the vaults and towers also agreed that they should continue to be responsible for those facilities. The microwave program will continue to pay the associated rent for its portion of vault and tower space.

Implementation Plan Schedule

- **The analog-to-digital upgrade project is currently executing according to plan –** The analog-to-digital upgrade project began in FY 1993/94. The DGS is currently executing the analog-to-digital upgrade in accordance with the previously developed route specific plans. The project is on target in accordance with the 1994/95 implementation schedule. The DGS does not foresee any significant issues that may negatively impact the remaining schedule.

The DGS is confident that the approach outlined in the 1994/95 PSMN analog-to-digital upgrade plan will provide its customers with the wide-area digital network services they require today and for the foreseeable future.